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A CONTRIBUTION TO THE LIFE HISTORY OF THE DIATOMACEÆ.

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Among the unicellular algæ, so-called, none have received more attention than the diatoms, and the interest has continued from two causes: the varied, and often very elegant, structure of their siliceous frustules makes them objects of beauty as cabinet preparations; while the delicate markings on their valves make them favorite tests of the performance of the best modern objectives.

Aside, however, from both these considerations, they have received a great deal of attention from many distinguished botanists and students; the results of whose labors may be found scattered through various scientific journals, and in costly and elegantly illustrated monographs. And yet, this long acquaintance with, and study of, these interesting organisms has but added, year after year, to the perplexity of the student; instead of making the study easier, it has been made more difficult from the introduction of an immense number of species and genera, based upon insignificant distinctions, so that the nomenclature, for the past half century, has been daily becoming more and more confused and unsatisfactory. A long familiarity with the diatoms, living as well as fossil, has convinced me that all known forms may be comprehended in a very few groups, and that even in these it is not difficult to trace a transition; and that all are built upon one general type, and undergo the same typical variations. In short, that the total number of genera should be reduced perhaps one-half, and of the species in far greater proportion.

The subject-matter of the present communication and that of other papers to follow has, in the shape of notes and drawings, been for many years waiting the "convenient season"; and so it has happened that some portions of what may be presented have meanwhile been independently noted, and published by others. It will be convenient to speak (I.) of the structure of the diatom frustule, the nature of its envelope, and the typical variations; (II.) the distribution and character of the internal contents; (III.) the motion of the diatoms, and (IV.) the reproduction and growth of the diatoms, with some general observations.

I. *The Structure of the Diatom Frustule, the Nature of the Envelope and the Typical Variations.*

The frustules of the diatoms are mainly siliceous, resisting the applications of acids and a glowing heat, but there is also more or less of a horny substance, probably the same as in spicules of sponges, and in the frame-work of the Polycystina. Sometimes the silex is wanting to such an extent, that the least treatment with acid, or heating, or even drying, will destroy the frustule; this is the case with the rare *Amphiprora complexa*, Lewis, and sometimes it is but partially present, as in *Fragilaria striatula*, W. S., which occurs in all conditions from having the smallest amount of silica, to one almost rigidly siliceous. Normally, the frustule is built out of a membrane, which is interpenetrated more or less completely with silex, and the non-siliceous or membranous part disappears on treatment with acids, or by prolonged incineration. Probably this membrane is similar to that which constitutes the so-called stipes, cushions and tubes of certain species, and to which the convenient name "gelatinous substance" has been given. All recent frustules become more or less browned by moderately heating; but the color disappears after prolonged burning, except when the horny substance is abundant, as is often the case in the hyaline centers of Heliopelta, Aulacodiscus, etc., which still remain brown after long burning, as do many of the larger siliceous sponge spicules, and also the siliceous frame-works of the Radiolaria. The tubes of Colletonema and Schizonema, the stalks of Achnanthes and of Gomphonema, become, in a similar way, dark by burning them moderately; they are simply carbonized, and the carbon disappears, as already stated in the case of the frustules, by greater heating, and an almost imperceptible ash remains.

All living diatoms have an outside investing gelatinous sheath, which, being structureless and perfectly transparent, is not usually recognized; but its presence may be readily demonstrated by means of fuschine. When a small crystal of this is applied at the edge of the covering-glass under which large diatoms are moving, long before the field is perceptibly colored, the ends of the frustules will become decidedly rose-tinted, and at the same time all motion is instantly arrested, and in a short time the color will be absorbed all over the frustule, and also by the cushions, stalks, and tubes, if these be present.

Plate I., *fig. 1*, shows a filament of *Fragilaria mesolepta* thus tinted, as also the slimy mass near by, and *fig. 2* represents the frustules and stipes of *Gomphonema olivaceum*, the latter of which may be compared with the filaments of cotton colored at the same time, and shown under the same enlargement in *fig. 3*. *Fig. 4* is the gelatinous sac enclosing diatoms conjugating, and *fig. 5*, a filament of Spirogyra. The outer cell wall of Closterium (a desmid) is tinted deep red by fuschine; but, unlike the diatoms, the cyclosis is not arrested; in fact, it is more clearly shown, and several streams of protoplasmic matter may be seen quite darkly colored, moving in parallel rows, now all in one, and now some in a reversed, direction. When a large diatom, *e. g.*, *Navicula major*, has been tinted with fuschine, the color is much more decided along the median line, or raphé, than it is elsewhere.

Whatever may be the composition of the secreted mucous envelope, there can be no doubt that it is a natural provision for the preservation of the living diatoms; it is an essential product of all living forms of this group of algæ, and out of it are formed tubes, stipes, cushions, &c., often so persistent and characteristic that many eminent naturalists have made them, to some extent, a basis for classification; but, after all, they are fleeting characters, and especially changeable as to form, as the following observations will show.

On the first day of February, 1859, I obtained from a small spring, issuing from a side hill, a gelatinous mass which was adhering to the sides of a conducting trough, and which upon examination proved to be an immense number of tubes, full of frustules of *Colletonema vulgare* which were moving inside the tubes with great liveliness. I transferred these to a saucer with pure water, and put a glass plate over, to keep out the dust. In a few days a slight pellicle or skin could be detected on the surface of the water, and a cleaned cover-glass, brought into contact with the water and removed, showed hundreds of the frustules, now out of the tubes, and on the seventh day of February I could not find a trace of a tube. A soft gelatinous and amorphous mass remained, which soon exhibited numerous papillæ projecting from the upper surface. This mass was full of frustules, and if they had been found thus in quiet waters, would have been called (as indeed up to the present time they are called) *Frustulia Saxonica.* Shortly, the summits of the papillæ became dark brown, or even black; here the frustules were congregated so densely that when a bit was snipped off and examined under the microscope, thousands, almost, were in the field at the same time. In a precisely similar manner, I have observed the tubes of Encyonema and the stipes of Gomphonema disappear in quiet waters, thus removing what has been hitherto, and even is yet, accepted as a generic character separating Cocconema from Cymbella. It is easy enough for one to see how the tubes of the Colletonema prevented the frustules from being swept away in running water, and the stalks or stipes of the Gomphonemæ, as also the cushions of the Synedræ, serve the same purpose. The mucous matter, which also constitutes the slippery coating of submerged stones or weeds, appears to be readily secreted in running water, and the frustules, moving freely forward and backward, form the tubes, or, by the collapse of the tubes, stalks or stipes by which they are securely moored or anchored; and, when neither tubes nor stipes are formed (which is rarely the case, except with those frustules that have a raphé on one or both valves), the secreted mass, out of which the frustule continually slips, forms, as with the Synedræ, more or less of a cushion, adhering to the stones or algæ, on which the frustules are sessile. The tubular character of the long stalks of the Gomphonemæ, or the Cocconemæ, may be readily recognized; and these, of course, are branched, whenever that self-division occurs from which they get the name "diatom." Sometimes, in the marine genera, tubes are formed within other tubes; and based upon this, Kutzing founded the genus Micromega, which we now know must be deleted. And, again, the whole genus Schizonema, which has been characterized by the forms of the fronds, *i. e.*, the varying forms of development of the tubes, which is a character of no specific value. The single species, *S. Dillwynii*, really embraces, perhaps, half of the whole number of Schizonemæ; and the remaining species may be reduced to one or two, the frustules of which are almost, if not quite, identical, the specific distinction having been founded on the variable growth of the fronds (tubes). The investing sheath or envelope possesses great elasticity, especially well shown with *Bacillaria paradoxa*, this diatom, which is really a Nitzschia, and, like all the other members of that family exhibiting lively motions, received its generic distinction on account of the persistence of the mucous sheath, so that, instead of falling apart, and exhibiting themselves as separate after division, the frustules cohere, and by their lively movements form, now a flat ribbon often curling in its own plane, and now, by shooting out end to end, a long line, and again rapidly retreating. These movements, when they are first seen, never fail to interest and even startle the observer; there is so much of apparent volition and activity, that one is almost to be pardoned for doubting for a moment the vegetable character. There is a small Amphora, often found sessile, or closely adhering to Bacillaria, a sort of parasite which rides back and forth undisturbed in the excursions of the larger frustules, as a small bug would ride on the outside of an elastic tube when drawn out and released in a gentle manner. The thin membrane stretched over the alæ of Surirella, and especially noticeable in *S. splendida* and its sporangial frustule (*S. nobilis*), is a portion of the investing sheath, and when iron carbonate is present in the water, as it generally is where these large diatoms abound, the membrane will be so strongly impregnated as to give a deep blue color upon testing with sulphuric acid and potassium ferro-cyanide; this will also happen to desmids gathered from ponds where the iron salt is in solution. The presence of an investing mucous or gelatinous sheath can also be demonstrated by observing large diatoms in a field colored blue by indigo, as I shall have occasion to note when treating of the movements of the diatoms. Besides serving, in the form of stipes, tubes, cushions, etc., to keep the diatoms from being swept away by torrents and tidal waves, the secreted envelope (slime or jelly, whatever we may call it) to some extent holds together the two halves of the frustule, and notably answers as a protection during conjugation, when the secretion is enormously increased, and which happens most commonly in early spring, or just at the close of the winter, in temperate regions. One may, at this time of the year, find, sometimes even under the ice, every submerged stick, stone, or blade of grass covered by an olive-tinted mass of mucus, which upon examination will be found to be a tangled mass of stipes of Gomphonema or Cocconema, producing tufts, sometimes half an inch in diameter; and as the frustules, with their beautifully arranged colored endochrome, push continually forward to the outside of the mass, the interior of these tufts will be left nearly or quite colorless. At the same season of the year, when all is activity in the rest of the vegetable world, another group of diatoms, which are not smaller at one end than in the middle and therefore do not slip out from the investing sheath to form tubes and stipes, but firmly adhere to each other after the self-division, may be found as long waving filaments, sometimes a foot or more in length, as Fragilaria, in running fresh water, and Melosira, in salt or brackish water.

Alkaline solutions appear to dissolve or disintegrate the mucous secretion readily, and I know of no more interesting experiment, if one would demonstrate the structure of the frustules, than watching the behavior of a large Pinnularia or Surirella under the action of a moderately strong solution of caustic potassa; when a drop of this is applied at the margin of the cover-glass, while one is watching the diatom under the microscope, the moment the solution reaches it the two halves of the frustules will slip apart, like the two halves of a box, one of which has been partly over the other as a cover. This box structure of the frustule is a characteristic feature of all diatoms; the top and bottom of the box, so to speak, constituting the valves, and the sides (of the cover and remaining half of the box) are the so-called "connecting membranes," "sutural zones," etc., more or less firmly (often very slightly), attached to the valves, and sometimes, when detached, termed "hoops."

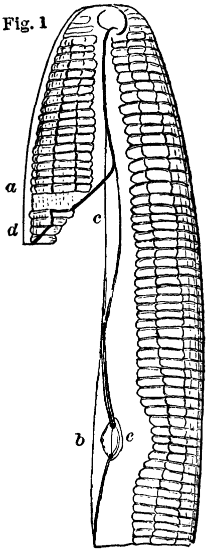
The sudden opening of the box, in the experiment with potash just described, is, perhaps, owing in part to a swelling produced by imbition of the solution (endosmose); but much more likely it is due to the normal tension of the internal mass inside its own elastic membranes, and only needing the removal of the outer sheath to cause the halves of the frustule to spring apart; the same tension, perhaps, causes the spindle-shaped forms (Naviculeæ) to glide forward and back like a shuttle, thus elaborating a more or less evident tubular structure, and the wedge-shaped forms (Gomphonemæ), and those with one margin more convex than the other (Cocconemæ), to glide always forward, forming stipes or stalks. In the preparation of specimens for study it is desirable to preserve as far as possible the fronds, tubes, stipes and cushions, and with the filamentous forms this is not difficult, as the membrane is tolerably well interpenetrated with silex, and the frustules of these will cohere pretty strongly even after a prolonged burning, forming cylindrical threads, as in Melosira, or ribbon-like bands, as in Fragilaria, or adhering in a zigzag manner, Diatoma; and though the tubes themselves of the Encyonemæ, Schizonemæ and Colletonemæ, may disappear, yet even here and after strongly burning, the arrangement and packing of the frustules will be quite apparent, and, by a more moderate treatment, the stalks of Gomphonemæ and Achnantheæ may be exhibited. Wet preparations of any of these, for exhibiting the mode of growth, will sooner or later be spoiled by leakage, or action of the medium on the tissues; and acid treatment should be eschewed, for this, though it may give a cleaner preparation of the valves, and exhibit more clearly the marvelous sculpture, will tear the frustules apart and destroy their arrangement. Preparations of this character may be compared to the handsome shells whose glowing pearl has been revealed by the destruction of the outer layers; pretty enough on a drawing-room table, but hideous in the cabinet of the naturalist. The true structure and beauty of the frustules is best preserved, upon the whole, in balsam mounted specimens, and this method of preparing them commends itself as also the most permanent. The remarkable character and amount of the mucous secretion is nowhere better seen than in the fronds of Schizonema, which vary from delicate branching threads to robust and tree-like forms, and from an inch to nearly a foot in length, and with varying shades of color from green to brown; and upon these characters genera and species have been founded, though insufficient, as is now generally acknowledged; the fronds may be preserved by simply spreading out and drying upon paper, like other marine and fresh-water algæ, and I have many original specimens from the herbariums of Kutzing, Lenormand, Brébisson, Greville, and others, in perfectly good condition.

We may consider, then, the diatom frustule as a siliceous box, one part, generally, slipping over the other, but sometimes with edges only opposed (the significance of this I shall show when treating of conjugation), and furnished with an external sheath, which serves, to some extent, to bind the halves together, and that so far all diatom frustules are alike. I shall now attempt to show that as to any points of difference, so far as they are known, they may be comprehended under three great groups, and again that each group will exhibit the same general variations from a typical form. The three grand groups I have termed, in the "Synopsis," which was published in the *Lens*, 1872, as (I.) the Raphideæ, (II.) Pseudo-Raphideæ, (III.) Crypto-Raphideæ; and M. Henri Van Heurck, in his elaborate work on the Belgian diatoms, and the most extensive and exhaustive since the days of Kutzing, has accepted this classification, and likewise has added, as an appendix to his treatise on the Microscope, a translation of the whole "Synopsis" as published in the *Lens*.

The three great groups are established upon easily recognized peculiarities in the stucture of the frustule, and though the transition is not, in all cases, a sharp one from one group to the other, yet, upon the whole, there is very little difficulty in assigning the group to which any particular diatom belongs, and the distinction is founded: (I.) On the presence of a true *raphé*, or, as it is sometimes called, median line; generally with terminal, and (more or less pronounced) median, enlargements or nodules. (II.) The absence of a raphé on the valves, but the presence of a pseudo-median line, often only a blank space, without the nodules or enlargements (the true raphé being along the edges of the valves); and all the forms belonging to these two groups are more or less bacillar, *i. e.*, the valves are much longer in the direction of the the raphé or pseudo-raphé. (III.) The entire concealment of raphé, and absence of a pseudo-raphé; and in this group the valves are generally circular, more rarely broadly elliptic, and often angular.

What is here termed a "*raphé*" is a true cleft, which in the typical form in group I. divides the valve symmetrically, and is undoubtedly the opening through which connection is maintained with the outer world. It was first announced as such by Schleiden, and any one making a study of living diatoms will readily recognize it. That it is a real cleft is quite apparent when one examines fragments of the valves of the large Naviculæ (Pinnulariæ), which occur in so many fossil deposits. Normally, in group I. the raphé is in the middle of the valve, and has both central and terminal enlargements (nodules), and is on both valves. *Fig. 1* represents a fragment of a valve of *Navicula major; c b* is the cleft or raphé, extending along apparently under and on one side of the central nodule *e;* in reality there is an elevated undulating ridge turned up at right angles to the line of the cleft, and which would scarcely be noticed in looking directly at right angles to the plane of the valve, and is, indeed, what one would ordinarily recognize as the cleft or median line itself, when the valve was unbroken. The upturned edges along the true cleft, which are very low in the Naviculæ, sometimes nearly or quite obsolete, become apparent as the keels or alæ of the Amphiproræ. And we find them also in group II., but now marginal as keels of Nitzschiæ, and alæ of Surirellæ, the raphé running along the edges of the valves; and here one will not fail to observe that when the departure of the raphé from a symmetrical position in the center of the valve, as in the typical Navicula, becomes excessive, having passed through the intermediate Cymbelleæ, where it is more or less eccentric or one-sided until it reaches the margin, we have a transition from group I. to group II. The drawing, *fig. 1*, was made carefully with the camera lucida, and will illustrate some additional points of structure. The central nodule, *e*, is not merely a thickened boss of silica; it is somewhat cup-shaped, as may be seen more readily in a view at right angles to the one given; it is hardly necessary to remark that Ehrenberg, and also Kutzing, erroneously considered these as openings. The undulating edge of the keel is shown by the curved line, to the right of the cleft line *b c;* and at *a* is a portion of the smooth sili-

Fig. 1

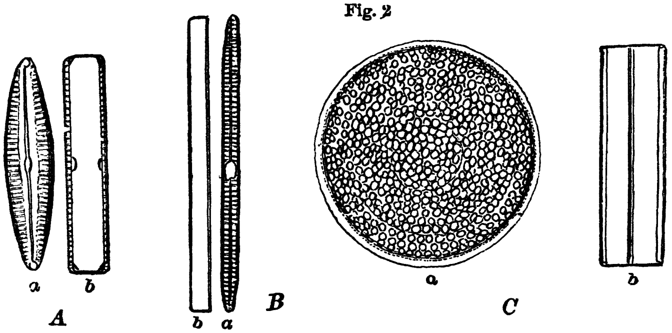


ceous valve, where two of the so-called pinnæ (ribs) have been removed; and at *d* the fractured edge of the smooth part of the valve can be seen running over the pinnæ, which project on beyond, and in fact lie on the under side (*i. e.*, next to the internal contents) of the valve, and are tubular with a middle opening; and here again one can fancy if these were but upturned and ran along the margin of the frustule, we would have something not unlike the so-called canaliculi of the Surirellæ in group II., and of which I shall have something more to say. While the raphé may be considered as the means of communication between the internal contents of the frustule and the outer world, yet more especially is this effected at the two punctæ, which may be almost always easily distinguished at the termination of the elevated edge of the cleft, each side of the terminal nodule. These punctæ are true openings in the valve, as I shall show presently, while the cleft itself is more tightly closed.

Group II. is normally represented by Synedra, and the frustules are mostly bacillar, and without median line or nodules; the former, however, is represented by an ala or keel running along one of the junction margins of the valves in Nitzschia, and all this group have a very lively motion when healthy; again in the Surriellæ we find the cleft along both margins of each of the valves, and these have not so lively a backward and forward motion, but more a lazy sort of roll. In Synedra, and the filamentous forms belonging to this group, the means of communication with the outside world are not so obvious; these are either sessile or remain, when separated, entirely quiet; they have frequently a line or blank space on the valves (a pseudo-raphé). The forms belonging to group III. have, normally, circular valves, and are generally so much developed as to the marginal zones or connecting membrane, and so persistently adherent after self-division, that they usually present themselves in this aspect when living, and which has been termed front view (f. v.). More rarely we find, in this group, forms with oval valves, *i.e.*, compressed frustules, or thimble-shaped, or cup-like; and sometimes with valves decidedly angular. If we take Coscinodiscus as the typical form, we shall find the frustule not unlike a pill-box, the sculptured valves being represented by the circular top and bottom of the box, and the connecting zones by its sides; and these valves are frequently as loosely attached to the connecting zone as are the top and bottom of the pill-box to the corresponding cylindrical portions. The communication with the outer world is effected, in this group, probably along the juncture of the valves and connecting zones; and one can readily perceive that in this case there can be no forward and back movement, as in groups I. and II.

It is to be noted that the connecting zone of these circular forms is not always an unbroken circle or hoop; it has often a cleft in it, as though one should take a flat ribbon of definite length and roll it into a cylindrical shape, just bringing the ends together, but not overlapping or even quite uniting them; in some species, however, the cleft does not extend through the whole breadth of the zone.

Fig. 2



In one or the other of these three groups, all known forms of the diatoms may be included, and it goes almost without saying, that genera naturally allied, so far as we can tell anything about them, will be brought together. Let us now consider the variations from a normal form; these follow the same laws in all the groups.

I give here what I consider as a normal form of each group. The figures are copied after Kutzing, because, although they are not as elaborately finished or as beautiful as more modern representations, they are characteristic and classic.

(*A*) *Navicula viridis*, E., is a typical form of group I., represented (*a*) in side view (s. v.), *i. e.*, showing the valve; and (*b*) front view (f. v.), *i. e.*, showing the sutural zone or connecting membrane.* (*B*) *Syneda ulna*, E., represents group II. (*a*) in side and (*b*) in front view. And (*C*) *Coscinodiscu spatina*, E., may be taken as a rigidly normal form of group III. (*a*) in side and (*b*) front view; all these are rectangular, or very nearly so, in front view, and consequently have the sutural zone, or connecting membrane, uniform in width, and the valves are symmetrical.

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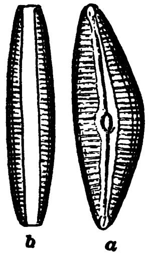
* "*Lucus a non lucendo.*" Kutzing calls them (*a*) Haupt side, (*b*) Neben side, which is better; but I retain the old names, as they have been so largely employed.

In all three groups we have by coherence of the frustules (otherwise normal) straight filamentous forms: thus in group I. we have Diadesmis, a genus founded alone on this character; in group II., Fragilaria, which is but an association of Synedræ in the form of a straight filament, and in group III. Melosira, which is a straight filament of frustules in no way to be distinguished from Cyclotella or even Coscinodiscus, except in cohering more or less firmly after the self-division of the frustules.

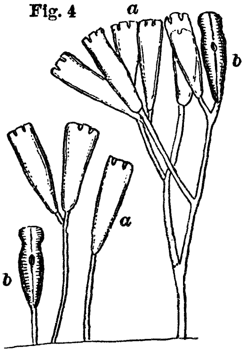
The first variation from a rigid normal type with flat valves (which rarely, if ever absolutely, can be found) is to one with valves more or less inflated, *i. e.*, when separated from the connecting zone, resembling shallow troughs in groups I. and II., and sometimes group III.; and also in this latter group, quite frequently, shallow circular dishes: this inflation or dishing can scarcely be called other than normal, as it is almost universal in all these groups, and the frustule is symmetrical throughout. The first marked departure consists in an unequal development of the sutural zone, by which it becomes wider at one extremity of the shorter axis, or of a radius, if the valve is circular; we may designate this as equatorially, in contra-distinction to the unequal development at the extremity of the longer axis, which latter we will term axially; both these are found in all three groups. In group I., when the sutural zone becomes widened equatorially, the raphé is more or less curved and no longer divides the valve symmetrically; and frequently the valve itself is lunate, *i. e.*, curved in s. v. This is the case with Cymbella (*fig. 3*), which represents *C. Ehrenbergii* (*a*) in side view and (*b*) front view.

Fig. 3



The portion of the sutural zone which lies along the more convex margin of the valve, and which is wider than that along the other margin, has been termed the dorsum, and the narrower portion, the venter; and though the terms, dorsal and ventral, truly have no proper application here, I shall, when necessary, continue to use them. The ventral portion of the sutural zone is nearly or quite the same width throughout as in a typical Navicula; but the dorsal portion is inflated and widest at the middle of the frustule, *i. e.*, at the summit of the convex margin, and when this width becomes excessive, as it does when Cymbella passes into Amphora, the frustule, when left to assume its position under influence of gravity, will lie on this expanded surface of the sutural zone, or on its back, so to speak, with the narrower portion of the sutural zone uppermost, and the two valves, with median lines and nodules, will both be in view at the same time, and the transverse section of the frustule will be trapezoidal, with more or less curved faces. Whether this unequal development of the sutural zone is really a proper basis for founding a new genus, is questionable; and, in fact, the various stages of gradation from Navicula with central raphé, and symmetrical and equally developed connecting zone, to one with raphé somewhat eccentric, and which has been termed Anorthoneis, then to one more or less marginal, as in Cymbella and Amphora, with a corresponding development of the sutural zone, are so easily to be traced, that these genera would almost seem to be but varieties of Navicula. In group II. we may take Epithemia, and in group III., Palmeria (Euodia), as representing the same modification, *i. e.*, an expansion of the sutural zone equatorially. In group I. a large number of Cymbellæ cohering, as in Ehrenberg's genus Syncyclia, will form more or less of a globular structure; and the same is true of Epithemia in group II., and notably so with Palmeria in group III. When the expansion of the sutural zone is axial, *i. e.*, at extremity of a long axis and at one end of the valve, the frustules always, and sometimes the valves, become more or less cuneate. In this case the raphé in group I. divides the valve symmetrically, but the central nodule is always nearer the larger end, as in *Gomphonema capitatum* (*fig. 4*), in side view (*a*) and front view (*b*); and it will be readily seen that the action of a contracting elastic sheath upon the frustule included in

Fig. 4



it, will be to slip or slide the frustule forward; and so we find the most if not all the cuneate species under this action are stipitate, attached at the smaller end to a stalk, and not merely sessile as are many straight forms. The same remark will apply to any forms with pointed ends, *e. g.*, Cocconema in group I., a genus to be distinguished from Cymbella only by being stalked. In group II. we find Licmophora and Rhipidophora with long stipes, and in group III. we have Podosira with highly convex valves, distinguished from Melosira by a pedicle. When the axial development occurs in group II., we have Meridion (*fig. 5*) and Rhipidophora (*fig. 6*); the former frequently, and the latter always, stipitate. Frequently, however, the frustules of Meridion cohere after self-division and, from their cuneate character, form circular or spiral filaments, which are very beautiful objects for the cabinet. I have found this latter species, sometimes, with the cuneate frustules alternating in position, and therefore, in this case, forming a straight filament. In the same group II. we have Surirella, which, in addition to the cuneate structure in front view, undergoes modifications in the form of the valves from cuneate to broadly oval, as in *S. Crumena*, and again to almost circular as in *Campylodiscus horologium;* the valves of the latter genus are often more or less flexed or saddle-shaped. The axial development of the sutural zone is rarely found in group III., and of course only when the valves are more or less elliptical; it may be seen, however, in Eucampia, and the cuneate form of the frustule in f. v. gives rise to a curved filament, as in Meridion.

Fig. 5

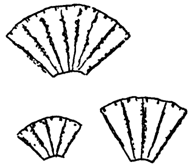
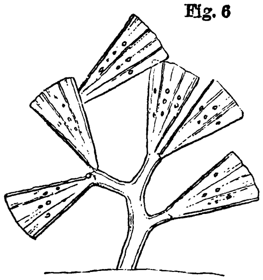


Fig. 6



There is another departure from the normal form in group I. which connects this group with the other two, *viz.*, the absence of the raphé or median line from one of the valves. When this happens, the frustule is curved in f. v., and the raphé and central nodule is on the concave valve, as in Achnanthes (*fig. 7*); also, in Achnanthidium and Cocconeis. And when the frustules are cuneate, as in Gomphonema, and the raphé is wanting to one of the valves, the whole frustule is curved in f. v., and the raphé is on the concave valve, a peculiarity upon which Grunow established the genus Rhoikoneis. In group I. there is another variation, tending to unite it with the other two groups, *viz.*, an extension or partial obliteration of the central nodule; it may be transversely as in *Stauroneis gracilis*, E. (*fig. 8*), or longitudinally as in *Berkeleya Harveyi*, Grun. (highly magnified) (*fig. 9*). In the latter case we may trace the change from the slight contraction of *Navicula rhomboides* (*Vanheurckia*), through one more pronounced in *Colletonema vulgare* (*Frustulia Saxonica*) to Berkeleya, and then to Amphipleura, where the nodule is obsolete; though even here a trace of the central nodule can be detected, if mounted in highly refractive media. All the last-named forms show, in addition to the linear extension of the median nodule by which it is constricted or drawn out more or less into a line, a corresponding enlargement of the terminal nodules, and the whole group have the valves finely striate. I have little hesitation in considering them all as varieties of the genus Navicula, and perhaps I may go further and say, of one species, *N. rhomboides.*

Fig. 7

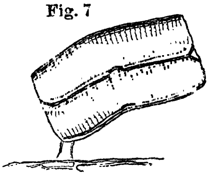


Fig. 8

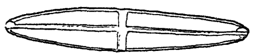
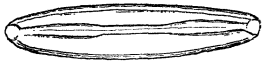


Fig. 9



In all the Raphideæ there is, as I have said, more or less of an upturned edge along the median line or raphé. It is noticeable in *Navicula major* and in many other large Naviculæ, and sometimes causes the valve to assume the appearance of having shorter striæ on one side of the raphé than on the other; a circumstance upon which Schumann founded the genus Alloioneis; unwarrantably, as it appears to me, for even if the raphé was one-sided, as in Grunow's genus Anorthoneis (which after all is only a Cocconeis, and this again a round Navicula sometimes wanting raphé on one of the valves), it could scarcely be considered as more than a variety. When the upturned edge is yet more developed, and becomes what is called an ala, we have the genus Amphiprora, in which the alæ and raphé may be either straight or, more generally, twisted; and in either case the frustule in front view, or partial front view, resembles in outline a figure 8. Rabenhorst termed those with twisted alæ Amphicampa, overlooking the fact that Ehrenberg had already given this name to quite a different diatom. Subsequently, he changed it to Amphitropis, and this name was accepted by Pfitzer, but has been very properly deleted by M. Petit. In some of the Naviculeæ, the median line is more or less sigmoid, and also, sometimes, the overlapping margins of the sutural zones. To receive this variety Grunow established a genus, Scoliopleura, which might be accepted as a designation of a sub-genus or variety of Navicula; and the same remark will apply to the name Pleurosigma, which has been given to a group which, in addition to a sigmoid raphé, has more or less sigmoid sides (shaped liked the letter S), obsolete, however, in *P. transversale.* To certain other forms with valves not symmetrically divided by a raphé, which latter is also arcuate, or with reflexed ends, the name Toxonidea has been given; and to yet others with frustules constricted, and allied to Amphiprora and Pleurosigma, the name Donkinia; all these are, at best, but sub-genera of Navicula. As in group I. we find frustules with the raphé absent from one of the valves, so also, in group II., there is something similar; *e. g.*, Entopyla has dissimilar valves, and so has Castracane's genus, Cyclophora, which bears exactly the same relation to Tabellaria as Rhoikoneis does to Gomphonema; *i. e.*, the one is but a variety of the other; and in group III. we find the same condition of unlike valves among the Chætoceræ. As a general rule the free forms belong to group I., the flat filamentous forms to group II., and the cylindrical, and most of the bizarre and irregular forms to group III. The sigmoid form of Navicula (Pleurosigma) in the first group is reproduced in Nitzschia in the second; and though, for obvious reasons, if the raphé in group I. is the channel of communication with the outer world, we should expect the frustules would be free, and not cohering to form filaments, yet even here we find exceptions, as in Diadesmis, and with larger forms, in Stauroneis; *e. g.*, nine or ten frustules of *S. acuta* have been found cohering after self-division, and filaments are not uncommon in genera with unlike valves, *e. g.*, Achnanthes and Achnanthidium, and also the allied Cocconideæ. It would not be very difficult to trace these changes from normal forms, if one had sufficient patience, and to show that a great many genera and species have been established on very slender foundations.

Fig. 10

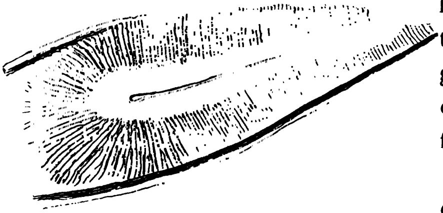


Fig. 11.

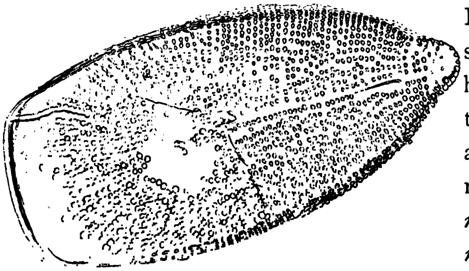
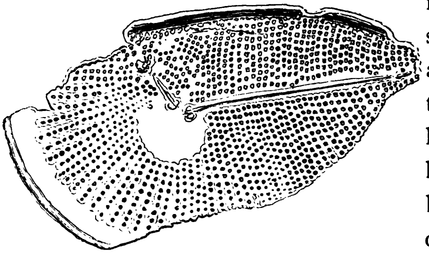


Fig. 12



I give now some reproductions of abnormal forms from photographs by Herr E. Weissflog. *Fig. 10* represents *Nav. permagna* with half the raphé wanting and the striæ on one side radially arranged. *Fig. 11* is an abnormal form of *Navicula maculata*, Edw. (*Stauroneis maculata*, Bailey, and *N. Johnsoniana*, Grev.), with raphé quite gone, except a small portion at one end; and one can readily imagine that if this had become obsolete the whole frustula would have assumed a circular or broadly oval form, with radiating punctæ, and would have been, in fact, a sort of Coscinodiscus. *Fig. 12* is still another abnormal form of the same diatom, showing the two portions of the raphé almost at right angles, and the subordination of the moniliform striæ or punctæ thereto; and one cannot fail to be reminded here of the peculiar markings of Aulacodiscus. Abnormal forms of this kind, which may reproduce themselves under favoring circumstances by the act of fissiparous division (and, perhaps, under certain environments be perpetuated after conjugation), are not rare; thus Janisch founded the genus Stoschia, which has only one species, *S. admirabilis*, or what appears to me to be but an abnormal *Coscinodiscus radiatus*, a fusion of two frustules, and a specimen of which I found among numerous frustules of this diatom in one of the soundings of the U. S. Steamship Narragansett; and I may add that all the valves had a little nodule, not quite central, upon the presence of which A. Schmidt established the species *C. nodulifer*. In the *American Journal of Microscopy*, vol. I., p. 82, Dr. Johnson figures an *Aulacodiscus Oregonus* with two centers; and there can be no doubt that "monstrosities" among the diatoms are not only common, but, in this low order of vegetable life, can be perpetuated. I once made a gathering of Synedra, in which nearly every frustule among thousands was distorted (the *S. hamata* of W. S. is of this character); and I have a gathering of Kutzing's *Cymbella excisa*, which is only the common *C. parvum* (*Cocconema*), with a small notch in the ventral margin. In group II. Epithemia has been found notched in a similar manner, and so has received a new name. Another variation from the normal form, and found in all three groups, is the occurrence of a greater or smaller number of internal plates (secondary or duplicate valves), a feature which has also served for the foundation of new genera. Thus, in group I., we have Ehrenberg's *Surirella craticula*, which is really a Navicula allied to *N. cuspidata*, but with internal plates perforated by large oval openings. It is not uncommon, and is perhaps either an extraordinary growth or a variation in the sporangial condition of *N. cuspidata*; I have found a marine form, *N. ambigua*, at New Haven, in this condition. Dr. Greville described a diatom from the South Pacific, which was evidently allied to the *N. Johnsonii* of W. S., having these same internal, perforated plates; and, recognizing the naviculoid structure, which seems to have escaped the notice of the author of the "*Synopsis of the British Diatomaceæ*," he established for it the genus Stictodesmis. Some time before this, Grunow had founded the genus Climaconeis to receive what he supposed to be non-cuneate forms of Climacosphenia, a diatom having the same internal plates; not recognizing the Navicula with true raphé and nodules. Subsequently, when it was discovered that Climaconeis was really Greville's Stictodesmis, the latter name was dropped, without reason as it seems to me, inasmuch as Greville *did* recognize the true structure; but then, when both names ought to be deleted it is not worth disputing about. We find also in group I. extra plates in the genus Mastogloia; here they are persistent, and so, in addition to the usual appearance of typical Naviculæ, the frustules show (in s. v.) what have been termed "loculi" along the margin of the valves, and the same is also to be observed among the Cocconideæ, especially *C. Grevillii;* these plates must not be confounded with extra valves, which are precisely like the normal ones, and which are not unfrequent in some species, *e. g.*, *Nav. clepsydra*, and the cause of which will be explained hereafter; nor must they be compared to the rugose sheaths around many sporangial frustules. These latter are external and readily separable, always falling off when full development is attained. In group II. we find these internal perforated plates in the genera Climacosphenia, Striatella and Rhabdonema. In this group they are usually called "septæ," and are often so numerous as to divide the frustules into many partitions. Similar plates are found in group III.; they resemble, however, more or less closely, the normal valves, though new species have been established on the variation. Thus *Halionyx undenarius*, Ehr., Janisch (*Actinosphænia splendens*, Shad.), and *H. vicenarius*, E., Janisch, which have been described as different species, are the same. A fine large specimen of this diatom, which I picked out from a washing of one of the soundings of the Tuscarora quite whole, and which had not been treated with acid, slipped apart by an accidental movement of the cover as I was mounting it in balsam, so that I obtained the valves separate. The two outer valves separated, and the inner valves of the frustule, quite differently marked, slipped out, but still adhering together; all this occurred in the mounting; all the valves had the same number of radial ribs, and the same hyaline center; they are accurately figured by Janisch (*Characteristik des Guanos*, T. I., *figs. 1, 2*).

Again, in group I. there is often an infolding or thickening of the ends of the valves, a sort of enlargement to be seen in front view, *e. g.*, in *Stauroneis Baileyi* and *S. acuta*, and also in various Gomphonemæ at the wide end of the connecting zone, and a little removed from the immediate margin; these enlargements, or vittæ, as they have been called, are common in group II., *e. g.*, in Meridion, and often when much developed they become imperfect septæ, as in Tabellaria and Grammatophora; and in group III. we find them forming the costæ or "music notes" of Terpsinœ and the intercostal plates of Porpeia.

In all three groups, after the valves have been separated by acid or other treatment, there may be accidental lodgment of smaller valves of the same or some other species within the larger ones, especially if the "hoops" still remain fastened to the larger valves. Of course this could not occur when a frustule is whole, but I have often witnessed it in half frustules, and it has sometimes been mistaken for new species. I have little doubt that the small frustules, figured by Grunow in *Ceratulus lævis*, var. *Chinensis* (*M. M. J.*, vol. 18, Pl. CXCVI.), are adventitious; the valves of this species, from their cup-like character, are very apt to hold smaller forms packed inside them, and I have a gathering of Podosira that shows inside the cup-shaped half frustules, very frequently, valves of *Grammatophora serpentina.*

From the foregoing it appears that, so far as the siliceous box or frustule is concerned, and its variations from a normal type, there is so much similarity in all three groups as to indicate a general law of growth and development, and a close connection; and though, as yet, there is no clear demonstration of a passage of the forms of one group into those of another, yet there is much that looks like it; and in any case, we must admit that what has been relied upon as specific character, is largely modified by the environment. I have not considered it worth while to discuss the question of "areolæ" or "bosses," or, indeed, at all, the intimate structure of the valves. A great deal has been published upon this subject, and some warm discussions have been indulged in. Doubtless the truth here, as elsewhere, lies between, and whichever view be adopted, it will not affect the present "contribution."

Many of the diatoms have, in addition to the slime-skin and siliceous plates already mentioned, other appendages, in the form of hairs, horns, or bristles, more or less siliceous, but not infrequently adventitious. These are rarely found upon any of the forms of group I.; they are more abundant in group II., and quite common in group III. Ehrenberg notices and figures something of this kind (copied by Kutzing, *Bac.*, Pl. VII., *fig. 11*), and considered them as organs of locomotion! It is pretty certain that what he observed was a parasitic growth not uncommon in Surirella and Nitzschia. In the case of *Stephanodiscus Niagaræ*, however, we have something which truly appears to be a development from the frustule itself. Gatherings of this diatom have been made especially by my friend Mr. S. Mills of Buffalo, in which nearly every frustule exhibited long hairs, flexible but brittle, apparently issuing from the marginal spines, and as long as, or longer than, the diameter of the valve; they are extremely fine, and readily detached or broken, and I am unable to conjecture what purpose they may have served; possibly there may have been an invisible membrane for which they answered as a frame-work or support, something like the *Coscinodiscus sol* of Wallich; but this latter, as I have found it, has the membrane quite distinct, and evident even after burning, though in this case corrugated and distorted. The appearance, however, of the Stephanodiscus, when fresh, with its clear and beautiful endochrome and these radiating hairs, is very striking; and as different from the ordinary acid-treated valves purporting to represent it, as Sir William Thomson's figures of Orbulina and Globigerina just from the tow-net, are from the dead shells of the bottom ooze. In group II., these siliceous hairs are found in Thallassiothrix; and in group III. they are extremely common and characteristic among the Chætoceræ where they become very stout horns or awns.

In addition to the hairs and awns, many diatoms are furnished with spines, marginal or sub-marginal and more or less persistent; on the presence or absence of these, species, and even genera, have been established; it is pretty clear, however, that in many cases their presence is a development due to certain surroundings. In group I., occasional spines (not often) have been observed on Navicula,—more common on Gomphonema, and, indeed, quite distinct on some of the larger fossil forms. In group II., we find *Surirella splendida* with two horns, and Brébisson termed these *S. Capronii.* In group III., *Coscinodiscus eccentricus*, E., and *Odontodiscus eccentricus* E., are the same diatom, the former without, and the latter with, spines; and characters founded on the presence or absence of these are of small value, as are also those based upon a greater or smaller number of radial ribs, or rays, or upon a coarser or finer striation. The Melosiræ often have the margins of the valves toothed or notched (Orthosira), and sometimes these and other forms, *e. g.*, Biddulphia, are hirsute, and in any attempt at a classification or improved nomenclature it will be safe to ignore these characters.

In regard to the frustules one circumstance is to be observed, *viz.*, the sporangial frustule of those species that have the connecting zones overlapping (like the cover upon a box) is about double the length of the parent frustule; while in the case of those that have simply edges brought together but not overlapping, the sporangial frustule is but little, if any, larger than the parent. These two differences of structure I had made out long before Mr. McDonald or Mr. Carter had published their views, and had corresponded with Dr. Greville about the same, and had sent to him my drawings, and later in the winter of 1867 I had also shown them to numerous microscopists in London, and among others to the well-known artist, Tuffen West. I do not, however, claim any priority, inasmuch as I did not publish anything until 1872; at which time, however, I was ignorant of Mr. McDonald's paper in the *Annals and Magazine of Natural History.* The delay in publishing was partly owing to the want of a microscopical journal in this country, and partly because I shrank from what Dr. Walker-Arnott used to call "rushing into print." Dr. Pfitzer has collected the references to the publications of those who have treated of the structure of the frustules in his "*Bau und Entwicklung der Bacillarien,*" Bonn, 1871, and he gives a diagrammatic representation, showing how continued self-division of the frustules produces thereby smaller and smaller individuals. It will be readily understood that the diatom valves cannot increase in size by age, only the hoops become wider by deposition of silex along the free margin; and, by the act of self-division, in all those forms which have overlapping connecting zones, the new valves with their zones will be smaller than the old ones, so that myriads of smaller and yet smaller forms are produced; and, therefore, some other process than this division is necessary for restoring the normal size: this is found in conjugation; by this act a frustule something like double the normal size is produced, and the cycle commences anew. In genera like Fragilaria, *e. g.*, which do not have overlapping zones, and which are mainly filamentous species, still adhering after division, the sporangium is not much, if any, larger than the parent frustules; but of this I shall treat fully when I come to speak of reproduction and conjugation. Dr. Pfitzer has proposed two groups, embracing all diatoms, and determined from the character of the endochrome; he calls these the "Placochromaticeæ" (mainly my group I., but also embracing Nitzschia, Surirella, Synedra, and Eunotia, of group II., and which should manifestly be separated from Navicula), and "Coccochromaticeæ" (containing the remaining forms of group II., and all of group III.). M. Petit has somewhat improved upon this classification, and I shall have something more to say about it when speaking of the arrangement and distribution of the endochrome.

To sum up the foregoing, it appears that for all diatoms there is a general type of structure, and that the departure from the normal form is regular and often quite gradual: and it is to be regretted that minute considerations, such as varied outline, difference in size, finer striation, abnormal forms, and the like, have sufficed so often for proposing new species, to say nothing about genera; whereas, looking at the subject from a more rational standpoint, and guided by safer principles of philosophizing, one may be well assured that nearly half the present admitted genera, and many more of the species, might be blotted out with advantage.

II. *Distribution and Arrangement of the Internal Contents.*

A summary of what had been, up to that time, published upon this subject, may be found in Mr. Julien Deby's excellent little brochure, "*Ce que c'est qu' une Diatomée*," extracted from the *Bulletin of the Belgian Microscopical Society*, 1877. I do not find however, quite such a structure as he has described. In a general way, and the first thing, indeed, that would strike an observer, the colored portion of the internal contents of living diatoms belonging to the same genus has a pretty constant and definite arrangement, but it is only in a general way. In some of the more important particulars all are alike or nearly so; and where there is a difference it is at once evident that the "build" of the frustule is different. No doubt both the endochromatic arrangement and the peculiar structure are due to causes not yet understood, and therefore neither the one nor the other can be accepted as a more natural basis of classification. So far as casual observation goes, there are, no doubt, in healthy living diatoms, two types of endochrome arrangement, one into broad plates or masses, the other into smaller (granular) portions. The former, the "Placochromaticeæ," and the latter, the "Coccochromaticeæ," of Dr. Pfitzer and M. Paul Petit; and the latter, in his essay on the classification of the Diatomaceæ, translated by Mr. Kitton, and read before the R. M. S., June 6, 1877, lays down two laws:

1. "The internal distribution of the endochrome is alike in all individuals of the same species."

This is correct, simply adding, "under similar conditions."

2. "The mode of connection of the endochrome with the frustule is common to all species of the same genus, and frequently to many genera, ***having an analagous structural development of their siliceous envelope***" (italics mine).

This is also correct, with the same limitation as the first; but one may, in view of the portion italicised, ask M. Petit wherein a classification, based on endochromatic arrangement which, as he implies, if not dependant upon, is at least coördinate with, structural development of the frustule, is a whit more natural than that proposed by those who have used this structural development. Nay, he falls back upon this himself, to meet deficiencies in his own endochromatic classification; inasmuch as it is not possible to examine living species always fresh, and all the fossil ones are, of course, entirely excluded. I do not intend to question that, in living, healthy diatoms, the same genera, upon the whole, have a similar arrangement of endochrome; and I will admit that a practiced eye can at once detect by this arrangement, *e. g.*, a small Nitzschia from a Synedra; but I do say, that the arrangement and quantity of "colored substance" is variable, and that it is not always possible to determine whether the same is most spread out upon the valves or on the zones, which is a character emphasized by M. Petit. Immediately inside the siliceous frustule, and, probably, firmly attached to it at certain places, lies a membrane which encloses the internal contents, and which, unlike the external membrane, is vitalized, and which, as the growth of the internal substance pushes apart the halves of the frustule, serves as the basis for supplying the silex for the inside edges of the sutural zones, and for the zones of the new valves; inasmuch as these are at first, or immediately after self-division, without these appendages.

Inside the membranous sac may be noticed, in all diatoms large enough to show the structure and arrangement of the internal substance, a light colored or dusky "central band," often distinctly granular, and conspicuous in front view, apparently holding together the valves and attached to or spread out more or less on the inner surface of the enclosing membrane directly under the inner surface of the valves, and also along the zones; it is capable of contraction and expansion, and in reality divides the internal substance, more or less completely, into two symmetrical parts by means of thin walls or membranes which issue from it, but which are not readily discernible. I am not prepared to say positively that this is always the case; but certain phenomena, to which I shall allude particularly when speaking of the motions of the diatoms, seem to indicate this; besides, as one may readily see in many large diatoms, if the endochrome is not obscured by adherence of organic matter to the outside of the frustule, and if it is not too highly colored by age, or confinement in vitiated water, there are very thin membranes, which are only to be recognized when seen edgewise, when they appear as threads, though, doubtless, there are also real threads, such as are seen in some of the Zygnemaceæ. In circular forms this band is quite central, and on an average it is in these about one-fourth the diameter of the valve; when seen in front view it appears somewhat constricted (shaped like an hour-glass), and occupying the middle of the frustule. When not tinted by overlying colored endochrome the band is almost colorless, and it is always well seen in large Naviculæ, and in the large Surirellæ. The chemical constitution of the band is quite different from that of other portions of the internal substance. Thus, zinc cloro-iodide, which changes the rest of the internal contents of the frustule to a pale green color without much contraction, indeed scarcely any in some specimens, produces a deep burnt-sienna color in the central band. The same reagent produces in *Closterium lunaris* and *C. Ehrenbergii* a dark bluish-green color, except at the isthmus, which, like the central band of diatoms, is colored sienna red. The ends of the diatom frustule are also by the same reagent colored red, indicating that a similar substance (whatever it may be), like that which composes the central band, is also spread entirely under the valves, but showing the color plainer where it is thicker, at the end.

I may remark further in regard to this substance composing the central band, that a prolonged burning, sufficient to remove all the rest of the endochrome, particularly in some circular forms, as *Stephanodiscus Niagaræ*, still leaves a dark central cord, the remains of the "band," stretching from one valve to the other, inside the frustule. Imbedded in the central band, a nucleus can generally be discovered, but I have not detected a nucleolus. In *Navicula* (*Pinnularia*) *major*, the nucleus is sometimes obscure, as it also is in many of the smaller Naviculæ, but in Stauroneis and Surirella it is quite distinct. In the large Naviculæ, especially *N. major*, in the central band seen in front view, there are often short radiate double lines, figured by Pfitzer in his work already mentioned. The significance of these I have not been able to make out, nor are they present in other large diatoms. The nucleus, as I have seen it, differs from the oil (?) globules which are found in the less dense and colorless portions of the endochrome, in not showing a bright central spot or dark marginal rim upon slight alterations of focus; nor does it give images of external objects as do the globules, but appears uniformly dark or light all over. The nucleus changes its position readily, and I have (rarely) noticed it oblong with a darker spot on one side.

The application of the chloro-iodide of zinc to a large *Navicula firma* produced a red tint apparently all over the frustule when seen in front view, but much more intense in the central band, the borders of which appeared almost black, while the general arrangement of the endochrome was not disturbed. Turning the diatom over to get it in side view, or that in which the valves are presented to the eye, I found that the general redness observed before was due to colorization of what was before colorless substance spread out along the zones and overlying the yellow endochrome; in this position (s. v.) the latter could be seen distinctly and but slightly changed as to color. A large *Cocconema lanceolatum*, treated in the same way, had the general endochrome unchanged; but towards the middle of the frustule the red color became distinct, and a part of the central band was deeply colored, almost obscuring the beautiful nucleus. What change appeared in these cases in the yellow endochrome seemed to be mostly due to the tint produced in the overlying and previously colorless layer. A very weak solution of the reagent is sufficient to color the central band quite distinctly, but still showing the nucleus inside clearly. The effect of the same reagent on a small Oscillaria was to tint it a dark brown with almost black granules, and each joint showed a nucleus like that of the diatoms. *Drapernaldia glomerata* was also colored dark brown approaching to black, with a distinct round mass in each cell, which sometimes, in the larger cells, was subdivided into eight portions. Not as much attention has been bestowed on the nucleii heretofore as could be desired, and I regret that some of the facts I am about to give have not yet been observed by others. In many diatoms there are constantly present two nucleii, in others but one. To the former group *Surirella splendida* belongs, and the appearance of the internal contents of a large specimen seen in front view and magnified 800 diameters is given in Plate II.

The two nucleii here are each apparently slightly imbedded in the central band. *Surirella elegans* has but one nucleus, and the appearance of this diatom in front view, and magnified 800 diameters, is given in Plate III. The double nucleus figured in Plate II., *Surirella splendida*, is not abnormal, nor has it arisen from a subdivision of the original one; it is always present, and in a gathering containing both these forms I could always distinguish the one from the other immediately, by the single or double nucleus. For many years I had near my residence an unfailing supply of these diatoms, and I am certain that the double nucleus was always present in *S. splendida*, which differs from *S. elegans* in structure of the frustule. Referring to Plate III. it will be noticed that the membrane enclosing the central band sweeps with a firm outline under the valves, and that between it and the valves lies the colored endochrome, the latter enclosed in a membranous sac, as can be demonstrated. The yellowish or colored endochrome is spread out under the valves, and its appearance in side view (s. v.), and also that of the central band and nucleus, is represented in Plate IV., *fig. 1*, which is *S. limosa* of Bailey magnified 600 diameters=*S. cardinalis*, Kitton, and probably *S. Guatimalensis*, E.[*] The cloudy patches of endochrome apparently floating in the colorless portions as shown in front view, Plates II. and III., are portions spread out along the zones and not in focus.

In *Stauroneis Phœnicenteron*, shown in s. v. and focused on the nucleus, Plate V., the central band expands along the zones, and also the endochrome, as shown by the darker shading. Here also we have a single nucleus, very distinct, and having a diameter of .0002″. Around the nucleus, in this diatom, the central portion of the band is gathered into lobes; and from the outer membrane enclosing these, something like threads may be discovered, which, in some cases, are edges of thin walls, as the globules may be seen gliding along them. In front view these threads are yet more noticeable, and I have seen them frequently opening from the plane of the nucleus to the extremity of the valves. These, I suppose, were the edges of the thin membranes, formed preparatory to self-division, and which subsequently approach at the ends of the frustules by growth of the internal substance lying between them and the valves, and so these membranes, extending through the cleft nucleus, become the walls upon which the deposit of silica will be made for the new valves.

Referring now to Plate IV., *S. limosa*, we notice the colored endochrome gathered into lobes, pointing centrally; but the converging points of the endochrome in all cases are not towards the nucleus but towards a "*germinal dot*," central in *Surirella splendida*, Plate II., which has two nucleii, but towards the larger end in *S. elegans*, Plate III., which has but one nucleus like *S. limosa*, Plate IV.

I have not seen this "dot" in other forms, and probably I should not have discovered it in Surirella but for the fortunate occurrence of these of large size where I could at all times obtain them, and in pure water, with the walls of the valves free from foreign deposit, and thus showing the endochrome clear and brilliant.

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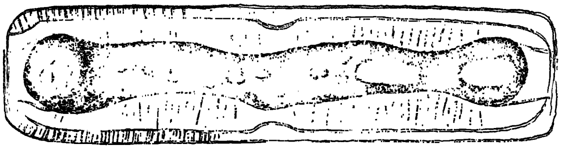
[*] NOTE.—Mr. Kitton, who has read this manuscript, adds the following: "This form has been referred to *S. Guatimalensis*, Ehr., by Schmidt, in his Atlas, in his description of the *figs. 11*, *12*, Plate XXI. *S. limosa*=*S. cardinalis* is *S. ovata*, Ehr., Mikrogeologie, Plate XXXVIII., A. 14, *fig. 10*. *S. Guatimalensis* is very much smaller and wants the hinge which is clearly shown in the figure of *S. ovata*."

The granular mass of the central substance, Plates III. and IV., is also strongly radiate towards the "dot," a structure indicated, perhaps, by the double lines in Pinnularia, as figured by Dr. Pfitzer.

In Plate II. a horizontal line is shown starting from one nucleus, and, perhaps, as was observed in *Stauroneïs Phœnicenteron*, this is the commencement of the membranes for self-division. In the clear space or colorless portion of the endochrome, as shown in all the plates, oil (?) globules, something of a higher refractive power than the substance in which they float, are to be seen in lively motion, not a regular cyclosis, but with a movement more or less interrupted; they glide along the membrane enclosing the central band, and, if they sometimes appear, as in Plates II. and III., within this, it is because the membrane incurves before reaching the interior wall of the zones. I do not remember ever seeing these globules pass from one end of the frustule to the other, as it would seem they might do if no partition wall intervened; as the balls approach the nucleus they move with an accelerated velocity, just as though the latter was ciliated.

Fig. 13



In Surirella the colored endochrome can be discerned in the so-called canaliculi, shown plainly in Plate II., and, somewhat enlarged, Plate IV., *fig. 2;* and we must suppose, therefore, that the thin membrane enclosing the colored substance, lines also the interior of the tubes, which are shown endwise in Plate IV., *fig. 8.*

By the application of a solution of bichromate of ammonia, one may observe the endochrome, still cylindrical, but pulled out of the canaliculi, and something analagous may be observed by a similar treatment in Navicula; in the latter case innumerable threads, I thought at first one to each pinna, were left, stretching from the rapidly contracting endochrome to the under surface of the valves when seen in front view (*fig. 13*). Soaking in water, and removing the reagent as far as possible, the endochrome again swelled, and could be seen passing upwards, as though the threads were tubes, the central band expanding under the valve at equal distance from the center, in circular forms, and longitudinally in bacillar or elliptic ones.

In Cocconema there is an additional cushion-like mass lying on the interior of the ventral zone under the central band (Plate IV., *fig. 4*). This diatom has two nucleii, and in early spring, and especially in recently divided frustules, much of the internal space is occupied by colorless protoplasm; the colored substance is spread on the zones, notably on the ventral one, and the aspect of the frustule at this time is peculiarly pleasing, from the perfect transparency and softness of outline of the clear colored portions. Later, the coloring substance increases in amount, and the frustules become darkened all over, and nearly the whole interior substance appears to be colored; seen in front view this is gathered into two lobes, represented in ventral aspect in Plate IV., *fig. 5*. The colorless protoplasm here not only bathes the sac, including the colored portion on the outer surface, and especially opposite to the central nodules, but it also lies between the lobes, nearly up to the middle, and the oil (?) globules here glide up and down. These lobes are again divided, as may be seen in side view (Plate IV., *fig. 4*), so that really four leaves or plates are formed, two of them lying on the convex, and two on the concave surfaces of the zones. Special care in focusing is requisite to observe this arrangement, and it is only with favorable specimens that it can be clearly made out; and also the endochrome must be highly colored, as it is always late in summer, or in individuals that have been kept living for a long time. Although in some of the Naviculæ the nucleus is beautifully distinct, in others, and especially in *N.* (*Pinnularia*) *major*, it is obscure. I have, however, seen it frequently in this diatom, and in one case as many as three, the middle one being the largest and most distinct. The central band itself is, in this diatom, quite distinct in front view, and generally shows, as I have said, a series of short double lines radially disposed, as figured by Dr. Pfitzer. It is quite evident that the water, and whatever it has in solution, comes first into contact with the membrane enclosing the expansion of the central mass, and is primarily active in the interior colorless portion, where the cyclosis (or something like that) of the so-called "oil globules" may be observed; and that the colored portion is elaborated, probably through the agency of the central portion and nucleus, appearing first as the "oil globules," which later are absorbed in the endochrome sac.

It has been supposed by some, and indeed it is so mentioned by Mr. Deby, in his paper already named, that communication with the outer world is effected along the sutural line, *i. e.*, where the zones overlap, or are in contact. This, I think, is not so. I placed *Stauroneis gracilis* in water colored with indigo (the ordinary water-color pigment). After leaving them several days I transferred them to clear water, and found them in the condition represented in Plate IV., *figs. 6* and *7*. The indigo had been absorbed along the median line, and particularly around the central nodule, where it had penetrated considerably inwards, as seen in f. v. (*fig. 6*, Plate IV.), and was also somewhat agglutinated on the outside; none of it had penetrated into the colored endochrome sac, nor indeed into the central band, but it was in the protoplasm and along the bounding membrane immediately surrounding the central band. Further proof that it is along the raphé or median line in group I., and the edge of the ala or keel in group II., that communication is effected with the outer world, will be given when treating of the motions of the diatoms.

The character and composition of the internal contents of the diatoms is yet imperfectly known. The coloring substance itself is readily extracted by alcohol, and its reactions and spectroscopic characters are mainly those of chlorophyl. The color of the alcoholic extract is somewhat different from that of chlorophyl; it has been termed phycoxanthin, but it is generally called "diatomin." When the alcoholic extract is concentrated, a yellowish green, waxy or oily substance is obtained, insoluble in water. Nitric acid causes this to gather into small olive-green globules, but produces no further change. Sulphuric acid at first changes the color to a deep bluish green and then dissolves it; upon heating the solution it becomes dark brown, nearly black, and when water is applied the whole breaks up into minute dark granules, which are soon re-dissolved and the acidulated water is colored brown by a perfect solution. With acetic acid, the color of the waxy mass deepens to orange, almost like the color of the original endochrome. With chlorohydric acid, the color becomes a still brighter green, but it appears to have no other effect. Iodine tincture simply browns it, and ammonia does not produce any change.

When living diatoms are treated with nitric acid, there is a considerable constriction of the colored substance which changes to a deep green with a shade of blue, while the colorless part becomes granular and full of dark specks, but the nucleus, within the central band, does not seem to be much affected. In *Nitzschia sigmoidea* there is a large central granular mass, which on the application of iodine water instantly contracts, becomes brown, and assumes the form of an elongated oval, the general arrangement and color of the endochrome, however, is not much disturbed; after a while the oval expands and becomes pale, and now the application of sulphuric acid causes it to assume the burnt-sienna red tint, and a corrugated outline, while the general endochrome becomes yellowish green, darker than in the natural condition; the same treatment caused the starch in the cells of Cladophora to become blue; an Anguillata became precisely the color of the central mass, and a *Navicula* (*Pinnularia*) *interrupta*, seen in side view, showed the general endochrome arranged along the zones on either side green, but the middle band, across the frustule, under the central nodule became strongly burnt-sienna red, as also the ends of the frustule, and the red tint *extended along the raphé.* It is quite evident that the reagent reaches, and acts upon, the central mass and the plasm sooner than it does the colored endochrome. But it is with the large *Surirella splendida* that one gets the best exhibitions, and those I experimented upon being from a pond where carbonate of iron was tolerably abundant, it is not to be wondered at that they gave me always a strong iron reaction. After slightly acidulating with sulphuric acid, the yellow-prussiate of potassa caused dark blue granules to appear in the central band, the nucleus still being distinct; the alæ became also a deep blue, as did the little patches of foreign matter adhering to the diatom, and which before, by their red color, indicated their iron-character. The nucleus of the Surirella carefully examined after the above-mentioned treatment, was decidedly bluish, and with a distinct blue outline; and the interior of the frustule, at its ends, where the endochrome was retracted was also blue, though the general arrangement of the endochrome was not much disturbed.

In Plate IV., *fig. 3*, the blue lines along the edge of the ala may be discerned, one of these running through the center of the "canaliculi." It is evident that here the communication with the outer world is effected, as along the raphé of the Navicule, and that the reagent reaches the central mass and plasm before it does the colored endochrome.

The application of the same reagents to a Closterium, obtained from the same pond, colored the outer cell walls deep blue; often the blue color was confined to one-half the desmid, the other remaining green, and almost always there was a blue deposit at the isthmus, sometimes broader than the diameter of the frond.

The application of chloro-iodide of zinc to the frustules of *Surirella splendida* caused a browning, especially around the nucleii, and at the same time the "dot;" and the membranous walls enclosing the central band, were all strongly marked; after a while the "dot" disappeared in the mass of colored granular matter, the general endochrome darkened, and, soon, strongly marked and tense radiating threads were visible in front view, and in some cases the portions of the colored endochrome that were drawn out of the canaliculi could be still seen retaining their form. With iodine water alone the nucleus and colorless parts became yellow brown, the granular mass and germinal (?) "dot" dark brown, and the immediate outline enclosing the nucleus a rich brown, the general arrangement of the endochrome remaining undisturbed. Subsequent application of sulphuric acid produced an intense darkening of the border of the colored endochrome, so that it appeared almost black, while the central mass became dark brown, but with the red nucleus still visible. After some time the colored portions were acted upon, and the frustule then became dark brown all over; doubtless much of this darkening of the colored endochrome was only apparent, probably the deep color of the plasm, and of the expansion of the central band along the zones and under the valves, masked it.

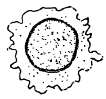
The action of sulphuric acid alone was variable; it caused a contraction of the colored endochrome without much alteration of the color, and a granulation of the colorless portion, and in a little while constriction and corrugation of the nucleii, and once I saw them divide, and dark granules appeared, lying on the colored endochrome.

In most specimens the nucleii disappeared after long treatment, though I have seen them still visible after three hours, at the end of which time the endochrome became a bright green.

I have frequently, by crushing the frustule, and especially after the application of reagents, obtained the nucleus outside the frustule, and moving freely in the water. Such a case is shown in the following sketch (*fig. 14*), which is the nucleus of a *Surirella elegans*, which had not been treated by reagents; it appears to have a portion of membrane yet adhering to it. Melloni's test caused this nucleus at first to increase rapidly in size; then it diminished, leaving only a ring, and not much over one quarter the normal size.

I have already alluded to the prompt action of caustic potassa. When a solution of this touches a large Surirella, instantly the interior mass swells, while at the same time the central band contracts, and also the bridge of endochrome, which is frequently to be seen in side view under the valves crossing the narrower portion of the frustule, as in Plate IV., *fig. 1*. The nucleus is driven along by the contracting walls and suddenly disappears; the frustule meanwhile splits open, generally at the larger end, and the colored endochrome flows out grass green, showing distinctly the corrugation of the enclosing membrane.

Fig. 14



A solution of sugar, applied to the same diatom, produced a very strong constriction of the colored endochrome, which, without any rupture of the frustule, was pulled out of the canaliculi distinctly, while the membrane, enclosing the central band and its expansion, was drawn together, so that the usually broad clear space in which the oil (?) globules float (see Plates II. and III.), became very narrow, and yet the circulation of these went on as lively as before, and continued until they were finally enclosed by apparent meeting of the bounding surfaces of the membrane. At this time long threads extended up to the canaliculi, and it seemed as though the membrane enclosing the colored substance had been stripped off from the under surface of the valves, and pressed downwards along the zones. The addition of sulphuric acid produced a deep blue, almost indigo, tint in the colored portions, and two large Naviculæ, lying near in the same solution, were colored, one indigo green, and the other a light green.

The action of fuchsine has already been noted; it is almost entirely confined to the outside. A rosy blush first appears, *e. g.*, at the end of *Navicula* (*Pinnularia*) *major*, and if we look at it in front view, very soon the tint may be observed all around the frustule, but stronger at the corners; later the whole frustule will be tinted.

I once noticed a remarkable disappearance of color. A large Surirella, which had been slowly dried under the covering-glass, showed no definite boundary of the endochrome; a slight, almost colorless mass was gathered at the smaller end, with a few dark granules in it, and the canaliculi were entirely colorless. Moistening again with water, the canaliculi were now colored pale green, and what appeared to be a large air-bubble occupied the interior of the frustule; this bubble slowly disappeared, and a green endochrome, with a sharply defined outline, but much wrinkled and folded, filled the interior of the frustule. After about half an hour the endochrome appeared to be drawn together at the center, around the "dot," and in some places pulled out of the canaliculi; one nucleus was distinct, though enlarged and granular. This experiment does not confirm the power of resuscitation claimed by M. Petit and others, of which more hereafter.

All the preceding experiments were made as early as 1865, and they are not as complete or as satisfactory as I could wish, and I have not had an opportunity of repeating them since.

The spectroscopic examination of the colored substance of living diatoms gave absorption bands, a dark one in the extreme red and fainter bands in the blue and green, so nearly the same as those of chlorophyl from different plants; that, so far as this test is concerned, we may consider them nearly, if not quite identical. The difference in color between the chlorophyl in plants and the colored substance in diatoms is indeed marked, but slight causes suffice to change that of the latter into the bright green of chlorophyl, and this without affecting materially the position of the absorption bands; doubtless the conversion of the colorless into the colored substance is attended by appropriation of hydrogen and fixation of carbon.

Every one has noticed, in warm weather, in not very deep water, where the surface of the stones is covered with the olive-tinted mucus or slime of the diatoms, innumerable bubbles covering the surface, often buoying up small masses which float on the water. I have collected these bubbles, and find them so rich in oxygen as to cause a perceptible increase of the glow of a burning spark plunged therein.

Nearly all the studies I have made of living diatoms have of necessity been upon fresh-water forms, as they were made at a time when I was living far away from the salt water; moreover, to observe the diatoms living for any length of time requires a constant supply of water; and for obvious reasons salt water is troublesome. The observations here detailed have been mostly made upon Placochromaticeæ, or those in which the colored endochrome is arranged in broad plates or masses, but the general structure is the same in the Coccochromaticeæ, *i. e.*, those in which, as in *Meridion circulare* and *Licmophora splendida*, the colored endochrome is gathered in smaller and somewhat rounded masses.

I believe that no forms with a true median raphé have this latter distribution of endochrome; it is only found in my groups II. and III. In Melosira and Striatella, and also in Biddulphia and some other genera of these two groups, the colored endochrome is collected into a number of oblong masses, arranged more or less radially; and, in some cases, particularly in Striatella, long radiating threads may be discovered extending to the four corners of the frustule and especially noticeable in front view. This colored radiate endochrome splits upon self-division of the frustule, and when in vigorous growth constitutes but a very small portion of the internal contents; so small, indeed, that viewed under low amplification the frustules look as though each one had a dark dot in the center, and hence came the trivial name *unipunctata*.

Max Schulte has given beautiful figures of this radially arranged endochrome and threads in Coscinodiscus and Denticella (Biddulphia) in Muller's *Archiv.*, 1858, showing also the central nucleus; and he also figures the curious arrangement into linear streams in Rhizosolenia.

Among fresh-water forms, *Stephanodiscus Niagaræ* exhibits the radial arrangement and the grouping into rounded masses beautifully. If it was always possible to examine living specimens, a classification based on endochromatic arrangement would, in the main, associate allied genera; but on the other hand, as the arrangement of the endochrome is always associated with peculiar structure or build of the frustule, it is more convenient to depend upon the latter, and far easier.

Too much study has been given to the mere structure of the valves, and the character of their markings, compared with what has been given to the living diatoms; the latter will be found far more interesting, and when the examination can be prosecuted under more favorable circumstances and with better optical means than I possessed, it may conduct us one step further towards unraveling the mysteries of the "beginnings of life." Minute as the diatoms are, yet existing even in our smallest streams in such countless millions, and multiplying with such enormous rapidity, they exercise an influence beyond estimation in purifying and revivifying the waters, unceasingly appropriating carbon and eliminating oxygen, and so fitting the waters for the purposes of higher life.

[END OF PART I.]

EXPLANATION OF PLATE I.

FIG. 1.—Filament of *Fragilaria mesolepta;* tinted with fuschine.
FIG. 2.—*Gomphonema olivaceum;* tinted with fuschine.
FIG. 3.—Filaments of cotton; tinted with fuschine.
FIG. 4.—Sac, enclosing *Cocconema parvum*, conjugating; tinted with fuschine.
FIG. 5.—Filament of *Spirogyra*, tinted with fuschine.
All × 400 diameters.

EXPLANATION OF PLATE II.

Surirella splendida, × 800 diameters, showing the two nucleii and germinal (?) dot; also the distribution of the endochrome in the canaliculi, and the arrangement of the lobes of the endochrome with regard to the germinal (?) dot.

EXPLANATION OF PLATE III.

Surirella elegans, showing the single nucleus and germinal (?) dot, and the radial distribution of the endochrome.

EXPLANATION OF PLATE IV.

FIG. 1.—*Surirella limosa*, Bailey, × 600 diameters, showing the single nucleus and germinal (?) dot, and the very marked radial arrangement of the endochrome around the latter.

FIG. 2.—Canaliculi of *Surirella splendida* in front view, showing the arrangement of endochrome.

FIG. 3.—Canaliculi of *Surirella splendida* in side view, showing the openings along the margin of the ala and the raphé (?); and the reaction, denoting presence of iron, after application of sulphuric acid and yellow prussiate of potassium.

FIG. 4.—*Cocconema lanceolatum*, front view, × 600 diameters, showing the two nucleii, and the gelatinous cushion, and the arrangement of the endochrome into two plates, spread out along the connecting zones.

FIG. 5.—*Cocconema lanceolatum*, side view, × 400 diameters, showing the further division of the plates of endochrome into two lobes.

FIG. 6.—*Stauroneis gracilis*, side view, × 600 diameters, showing the imbition of indigo at either side of the central nodule.

FIG. 7.—*Stauroneis gracilis*, front view, × 600 diameters.

EXPLANATION OF PLATE V.

Stauroneis Phœnicenteron, × 800 diameters, showing the stellate arrangement of the central granular mass around the nucleus, also the radiating threads or edges of thin membranes, and the distribution of the endochrome along the walls of the connecting zones.

PLATE I.

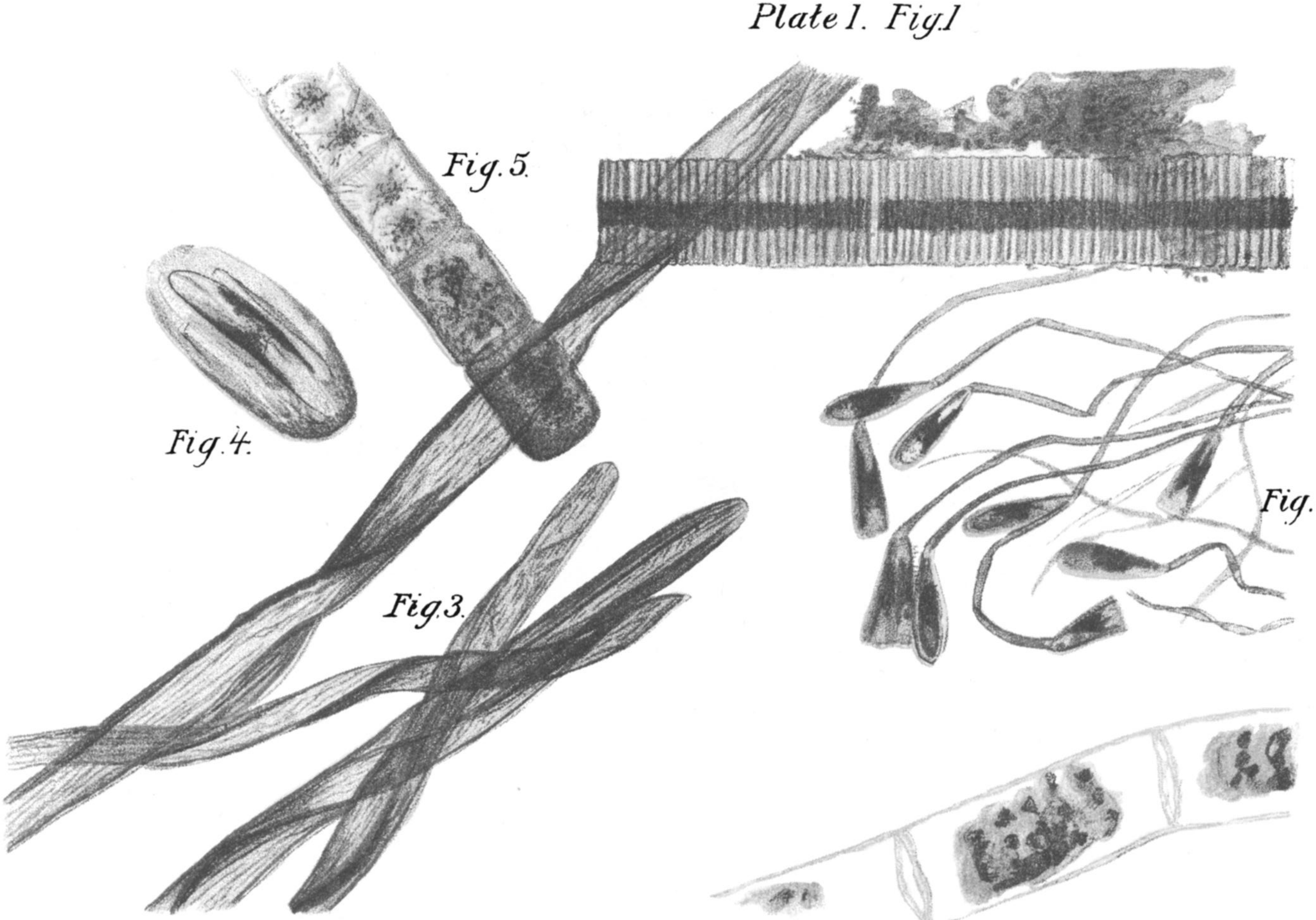


Plate 1. Fig.1
Fig. 5.
Fig. 4.
Fig. 3.
Fig. 2.

PLATE 2.

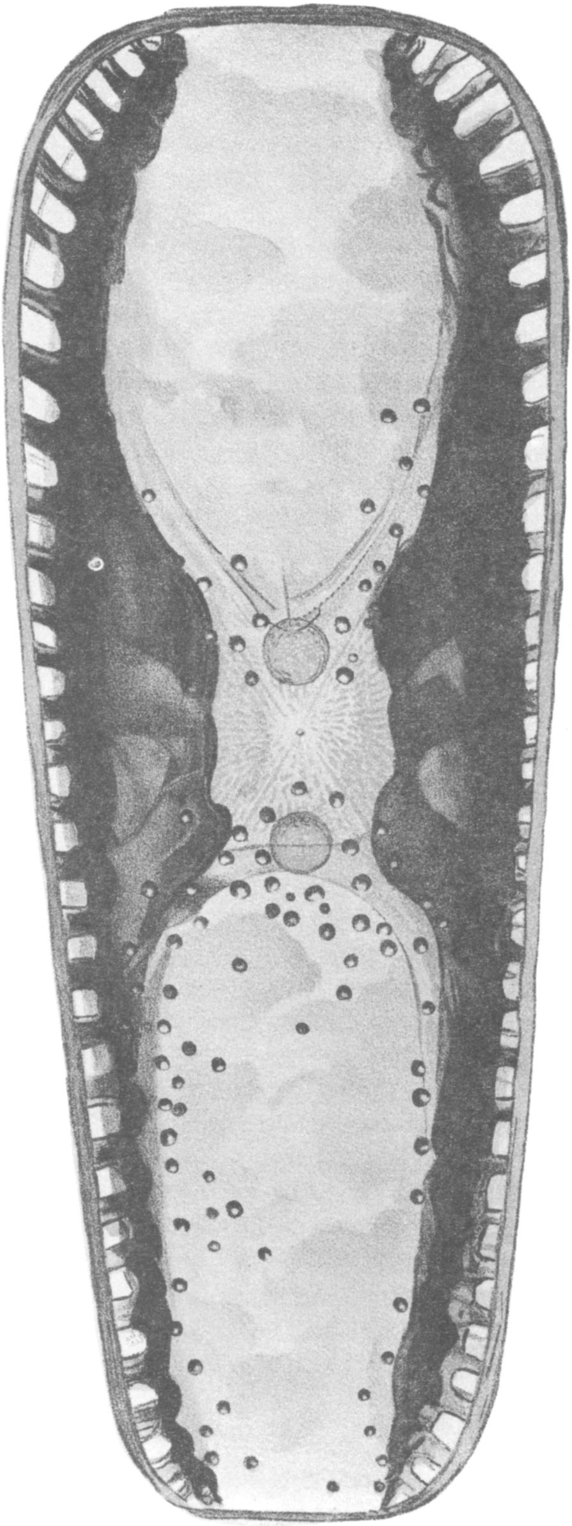


Plate 2.

PLATE 3.

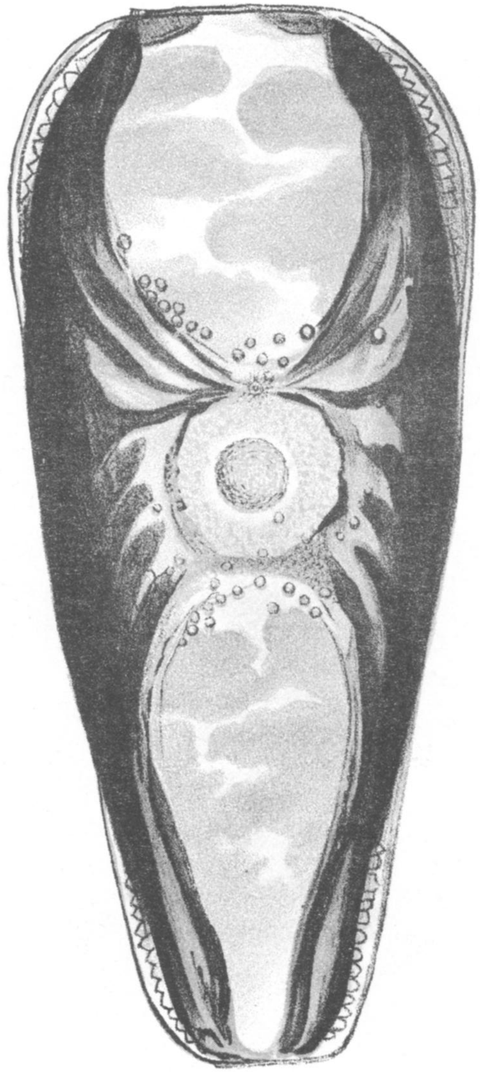


Plate 3.

PLATE 4

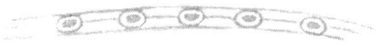


Fig. 3.

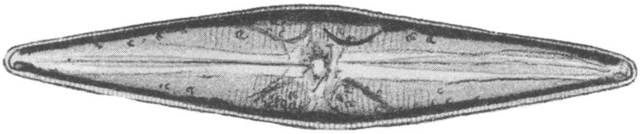


Fig. 7.

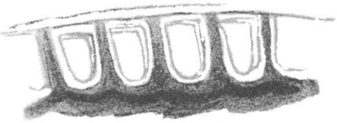


Fig. 2.

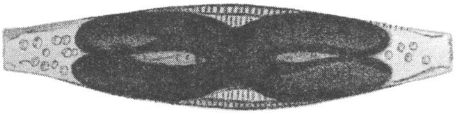


Fig. 5.

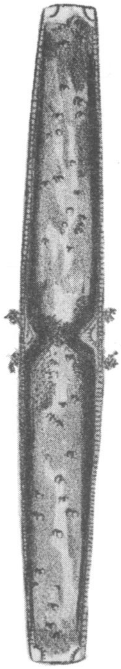


Fig. 6.

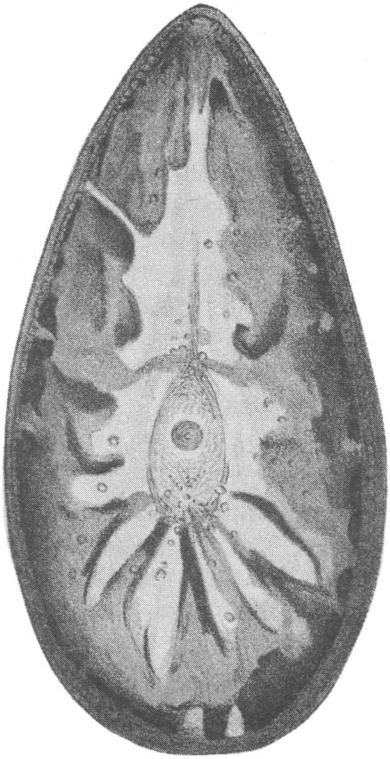


Fig. 1.

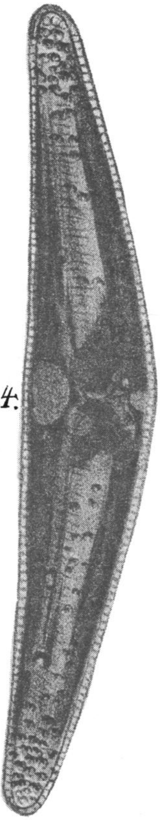


Fig. 4.

Plate 4.

PLATE 5

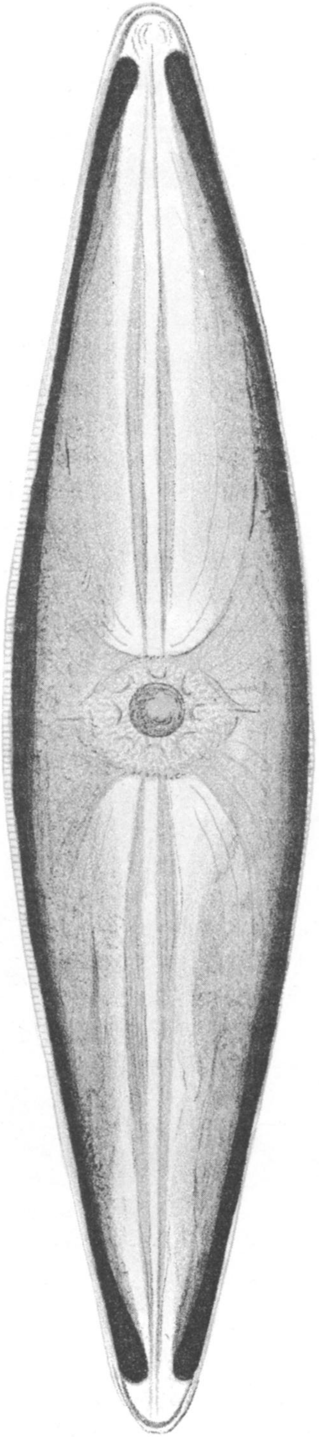


Plate 5.